SPREAD OF RED-BANDED MANGO CATERPILLAR, *DEANOLIS SUBLIMBALIS* SNELLEN (LEPIDOPTERA: PYRALIDAE), IN CAPE YORK PENINSULA, AUSTRALIA

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Abstract

Deanolis sublimbalis Snellen (red-banded mango caterpillar) is a serious pest of mango (*Mangifera indica* L.) fruit. In 1990 it was first recorded in Australia in Torres Strait and in 2001 it was detected on the Australian mainland in the Northern Peninsula Area (NPA) at the tip of Cape York Peninsula, Queensland. Results from annual surveillance conducted from 2001-2007 in the NPA indicated that *D. sublimbalis* was spreading through natural adult dispersal at an average rate of 7 km/year. This provides the first record of this pest's rate of spread, the understanding of which is necessary in formulating control strategies.

Introduction

Deanolis sublimbalis Snellen is a pest of mango (*Mangifera indica* L.: Anacardiaceae) fruit in South and Southeast Asia, Papua New Guinea (PNG) and, recently, the northeastern tip of Australia. The larvae infest mango fruit from marble size to maturity (Zaheruddeen and Sujatha 1993), feeding on both the flesh and the seed and rendering fruit inedible.

D. sublimbalis has three to four generations per year, completing its lifecycle in a month during mango fruiting season (Fenner 1997, Sujatha and Zaheruddeen 2002). The adult lays its eggs mainly on the peduncle of the fruit (Krull 2004). There are five larval instars with the first and second instars feeding on the flesh and third to fifth feeding on the seed (Golez 1991, Krull 2004). *D. sublimbalis* undergoes pupal diapause in the trunk of mango trees and there are indications that adult emergence is triggered by the onset of flowering (Pinese 2006). Adults have been detected from June to December in PNG (Gibb *et al.* 2007). *Mangifera indica* is the only known host of *D. sublimbalis* in Australia. Other hosts include *Mangifera minor* Blume, a wild fibrous mango found in Indonesia, PNG and the Solomon Islands (Tenakanai *et al.* 2006), *Mangifera odorata* Griffith (kwini) in Indonesia and *Bouea burmanica* Griffith (maprang) in Thailand (Waterhouse 1998).

The known distribution of *D. sublimbalis*, together with years of first detection in individual countries, is shown in Fig. 1. Date of detection may be later than date of actual arrival in Southeast Asian countries due to absence of systematic surveillance. *D. sublimbalis* was first detected in Australian territory on the Torres Strait island of Saibai in March 1990 and its movement through the islands was monitored in subsequent years until its arrival on the Australian mainland in 2001 (NAQS 1999, 2003) (see Fig. 2).

D. sublimbalis can spread short distances by natural dispersal of adult moths, or long distances through either human-assisted movement of infested fruit or dispersal of adults on the wind. Its potential for spread and crop damage are of concern to the Australian mango industry which has an estimated annual value of AUD $100 million (AMIA 2006).

This paper reports the rate of spread of *D. sublimbalis* in the Northern Peninsula Area between 2001 and 2007. Modes of spread of *D. sublimbalis* adults and larvae are also discussed.

Surveillance method for *D. sublimbalis* larvae in Queensland

In response to the Hammond Island detection in August 2001, surveys of roadside feral mangoes and trees in communities in the NPA, greater Cape York Peninsula, the urban centres of Cairns and Townsville and mango production region of the Atherton Tablelands were initiated in October 2001. These were continued annually during the peak fruiting season between September and November until 2008. Fruit was either picked or collected from underneath trees and those exhibiting external damage were cut to ascertain the presence of *D. sublimbalis* larvae. Originally, mangoes in any condition were cut open to detect *D. sublimbalis*. However, after several years of using this sampling method it was apparent that *D. sublimbalis* was only found in fruit exhibiting some external signs of damage. As the purpose of the surveillance was to delimit the extent of *D. sublimbalis*, each successive year's surveillance focussed on surveying mangoes outside the bounds of the previously known infested area. Mango trees that were previously free of *D. sublimbalis* and outside a known infested zone were re-surveyed in subsequent years.

Samples of *D. sublimbalis* larvae were collected in 70% ethanol and returned to the Cairns laboratory for positive identification. The first samples collected at Somerset in 2001 were confirmed by DNA analysis at CSIRO laboratories in Canberra, with subsequent samples confirmed by the QPIF diagnostic entomologist by comparison with voucher specimens.

Results

In October 2001, 350 mango trees were surveyed in the NPA. *D. sublimbalis* was detected in feral mango trees at Somerset and found to be confined to approximately 60 mango trees in three locations, all within 1 km of each other. Larvae were readily detected in fruit between 4 and 12 cm in length, both on the tree and ground, with up to four larvae being found in several fruit (Foulis *et al.* 2001). Results of subsequent years' surveillance are shown in Table 1 and Figs 3-8. By 2007, *D. sublimbalis* had been detected in all areas known to harbour mangoes in the NPA. *D. sublimbalis* was not detected at other sites surveyed on mainland Queensland outside the NPA between 2001-2008.

From 2001-2007, *D. sublimbalis* had an average rate of spread of 6.9 km/year in the NPA (Table 1, Figs 3-8). The lowest rates of spread in a year were from Bamaga to New Mapoon (2.1 km in 2005) and New Mapoon to Seisia (2.2 km in 2006). Annual spread in a west to southwesterly direction was further (3.9-14.5 km) than that in a northwesterly direction (2.1-2.2 km). *D. sublimbalis* took two years to spread 7.7 km from Injinoo to Muttee Heads. The mangoes at Muttee Heads are an isolated group, with no known mangoes between them and the next nearest mangoes at Injinoo.

Table 1. Spread of *D. sublimbalis* in the Northern Peninsula Area (* denotes feral mango sites).

Nearest prior detection (Place and Year)	New detections (Place and Year)	Number of mango trees surveyed	Maximum distance from (and time since) nearest previous detection	Rate of spread (km/ year)
Somerset (2001)	Lockerbie, Punsand Bay, Roma Flats* (2002)	624	14.5 km (1 year)	14.5
Lockerbie (2002)	Blue Valley* (2003)	303	5.5 km (1 year)	5.5
Blue Valley* (2003)	Bamaga (2004)	342	7.6 km (1 year)	7.6
Bamaga (2004)	Injinoo, New Mapoon, Umagico (2005)	212	7.7 km (1 year)	7.7
New Mapoon (2005)	Seisia (2006)	68	2.2 km (1 year)	2.2
Injinoo (2005)	Muttee Heads* (2007)	122	7.7 km (2 years)	3.9
		Average rate of spread (km/year)		**6.9**

Discussion

Spread on mainland Australia

The extent of the *D. sublimbalis* infestation in the Somerset area suggested that the incursion had been present for longer than one season. The last reported sampling of mango fruit at Somerset was approximately eight years previously by a NAQS survey team (Foulis *et al.* 2001).

While *D. sublimbalis* can potentially be spread considerable distances by people carrying infested fruit, its dispersal via this means would have resulted in the establishment of populations in the indigenous communities prior to those in isolated sites such as Roma Flats and Blue Valley. The appearance of *D. sublimbalis* in unpopulated areas suggests that spread in the NPA has resulted from natural dispersal of adults rather than by human intervention, even though anecdotal evidence suggests that infested fruit has been transported for human consumption in the NPA.

The higher rate of dispersal in a southwesterly direction compared with a northwesterly dispersal could be due to the availability of host trees. However, *D. sublimbalis* has not yet been detected in two mango trees at Cape York north-west of Somerset (last surveyed 2008) and this may indicate that spread is influenced by prevailing winds and associated with fruit odour casting. Winds in this region are southeasterly for most of the year and northwesterly from December to March (BOM 1999). Adult populations are known to peak in September and October and have diminished by December (Gibb *et al.* 2007, Yarrow and Chandler 2006) and are consequently subjected to southeasterly winds. It has been suggested that insects maximise odour scanning by flying across prevailing winds (Linsenmair 1968, Bell *et al.* 1995) and this may explain the dispersal of *D. sublimbalis* in a southwesterly direction, *i.e.* across the prevailing southeasterly winds.

While this NPA example gives an indication of rate of spread, it has not been possible to correlate dispersal with host availability, largely because of the unknown distribution of feral mango trees in forested areas of the NPA. It is likely that limited host availability has affected the dispersal rate of *D. sublimbalis* in the NPA (*e.g.* the relatively slow spread over the 7.7 km mango-free area between Injinoo and Muttee Heads), so care must be taken when extrapolating these data to urban or commercial production areas where host availability is not such a limiting factor. Krull (2004) found in PNG that *D. sublimbalis* spreads on the original tree first and then onto other trees, indicating that spread within an orchard is slow.

Comparative rate of spread elsewhere

There are no other references in the literature to *D. sublimbalis* dispersal. However, a rate of spread in India may be inferred from historical detections using time and distance between successive detections. Historical records and the relationship between the date and distance from first detection and subsequent detections have been used previously to calculate the rate of spread of gypsy moth in North America (Liebhold *et al.* 1992). While the distribution of mango trees, time of *D. sublimbalis* presence prior to detection and mode of spread are unknown in India, the consistency in the inferred rates calculated from chronological detections, plus the absence of *D. sublimbalis* records in the literature on insects of agricultural importance in India prior to each detection (Waterhouse 1998), supports the assumption that first detection approximates first arrival.

Based on time to spread between all known *D. sublimbalis* detections (from Darjeeling to Calcutta, to Puri in Orissa and to Godavari in Andhra Pradesh), an average rate of spread of 15 km/year is inferred for India, with a range of 13-18 km/year. While the history of *D. sublimbalis* detections in Papua New Guinea is less well known (Waterhouse 1998), it is included here for interest as the inferred rate of spread is not dissimilar to that of India. Based on the time to span the shortest distance between each successive detection in PNG, the average rate of spread was 13 km/year, with a range of 3-19 km/year (see Fig. 1 and Table 2). Although somewhat speculative, these inferred rates are included for comparison, as they are not vastly different from the rate of spread found in the NPA and offer the only other indications of *D. sublimbalis'* potential dispersal rate.

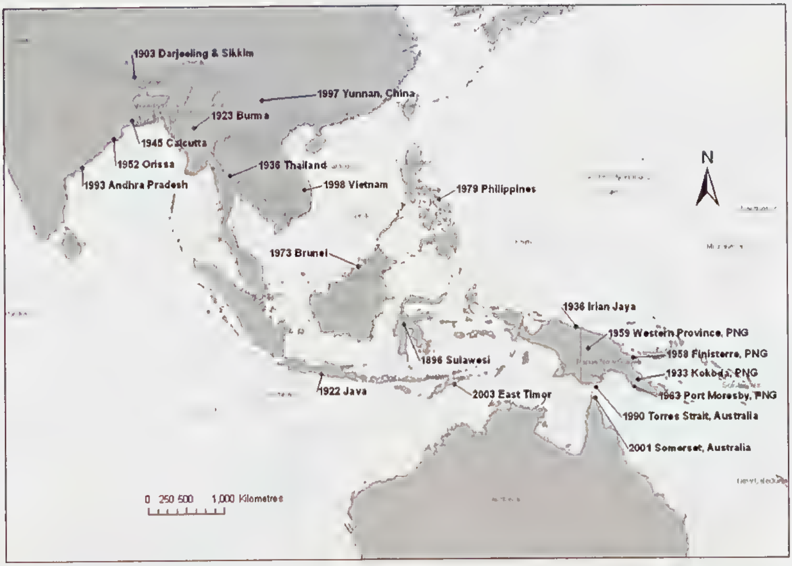


Fig. 1. Known distribution of *Deanolis sublimbalis*, with years of first detection (Leefmans and Van der Vecht 1930, Sengupta and Behura 1955, Li *et al.* 1997, Waterhouse 1998, Van Mele *et al.* 2001, Bellis *et al.* 2006).

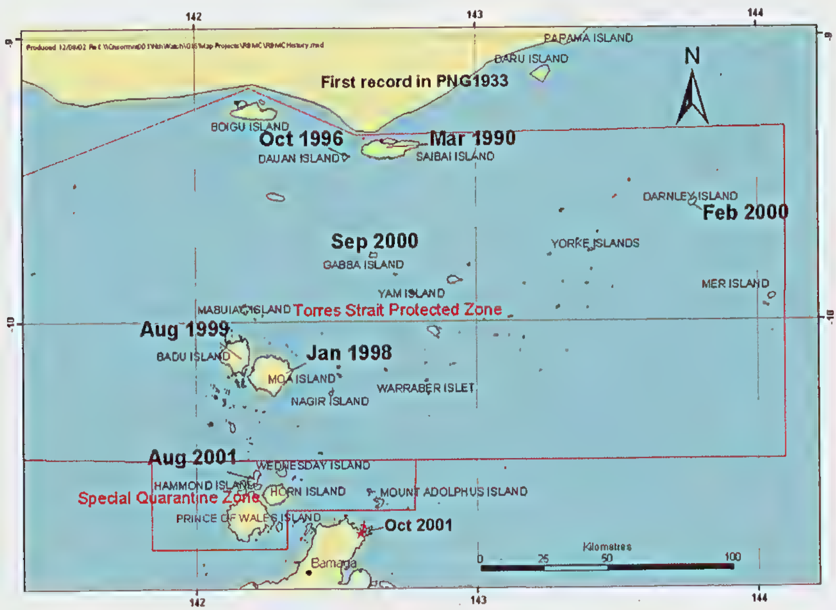
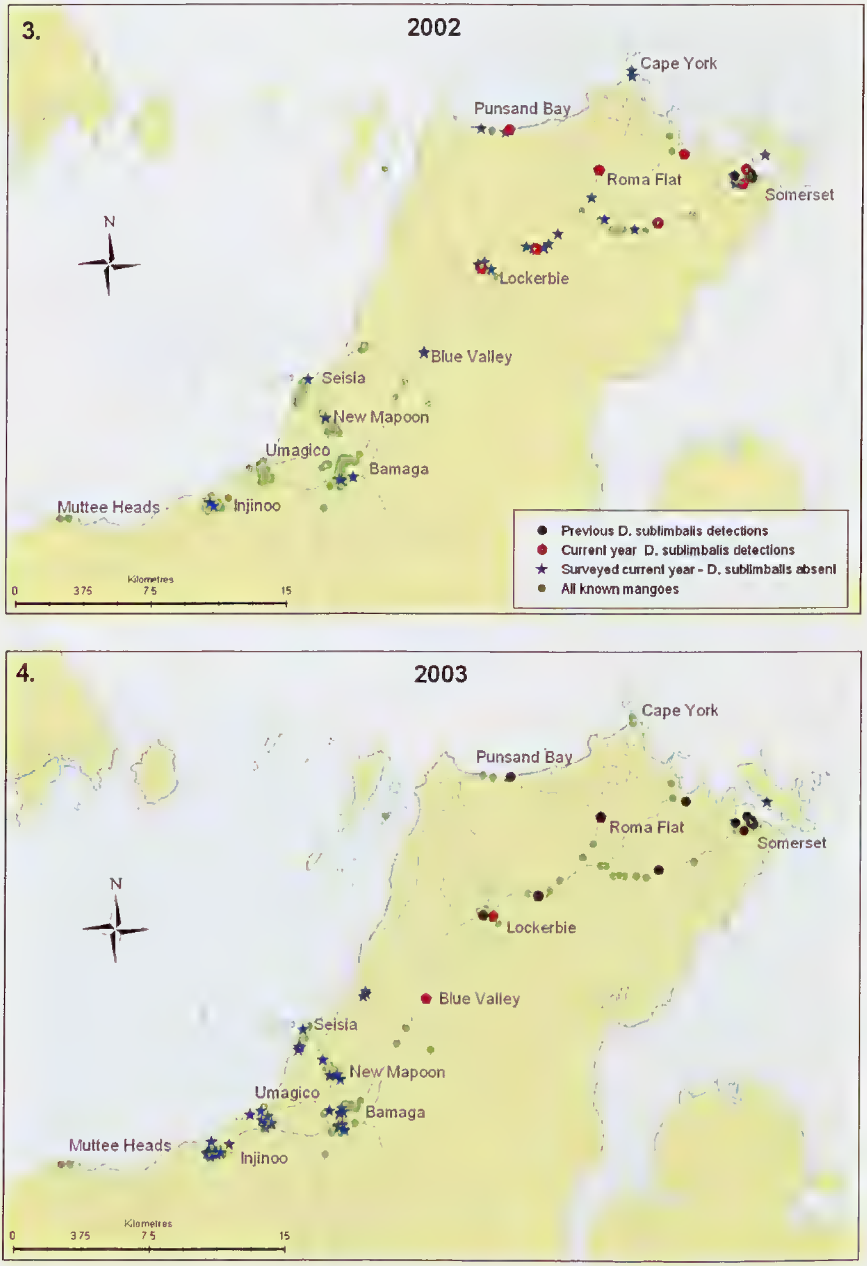
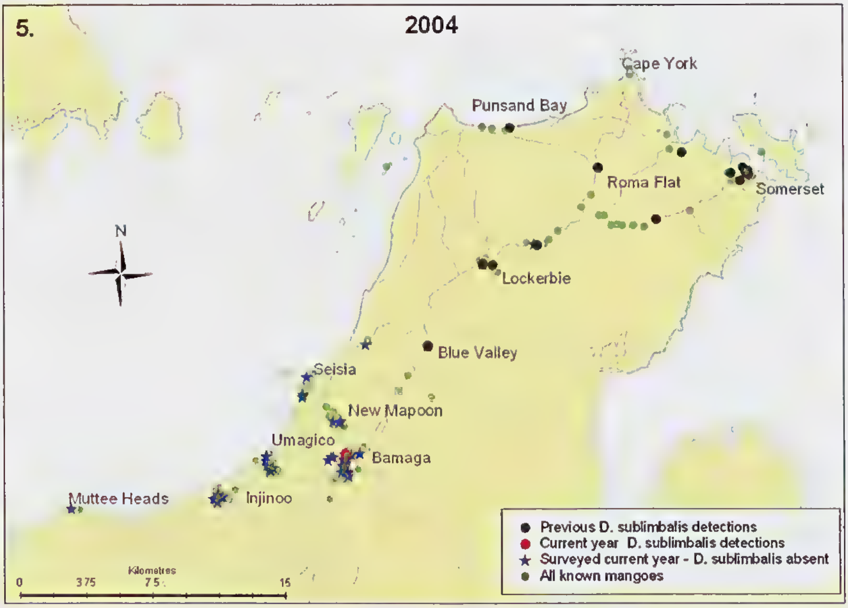
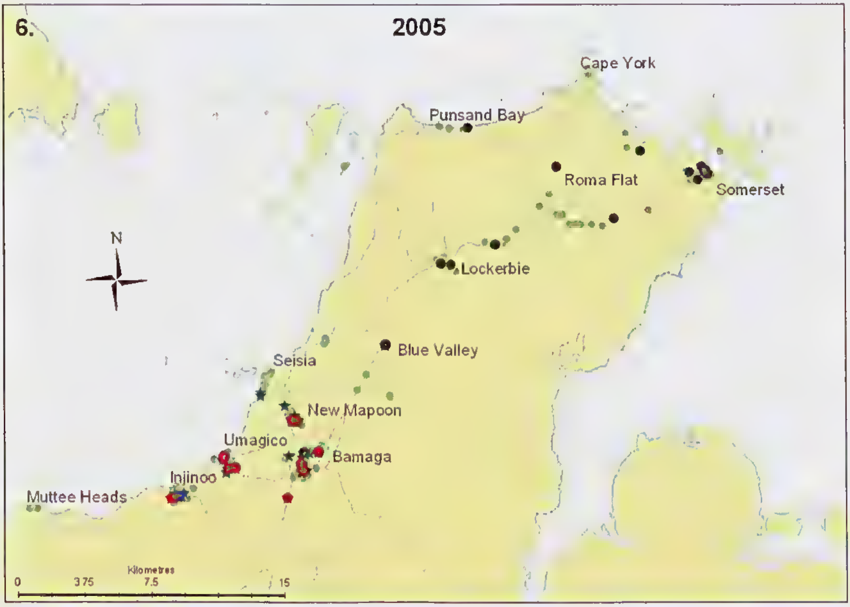


Fig. 2. Spread of *D. sublimbalis* through Torres Strait.

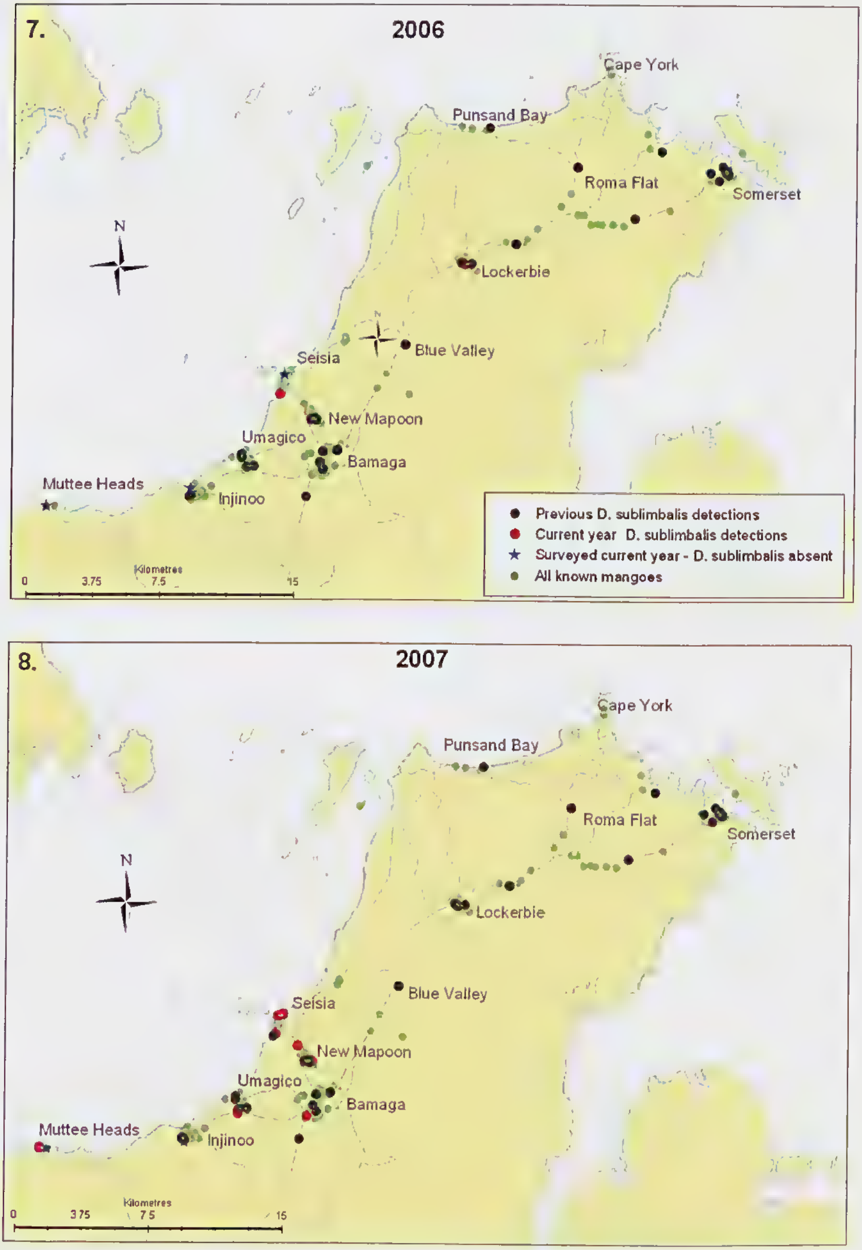


Figs 3-4. Spread of *D. sublimbalis* through Northern Peninsula Area of Cape York Peninsula, Queensland, 2002-2003.





Figs 5-6. Spread of *D. sublimbalis* through Northern Peninsula Area of Cape York Peninsula, Queensland, 2004-2005.



Figs 7-8. Spread of *D. sublimbalis* through Northern Peninsula Area of Cape York Peninsula, Queensland, 2006-2007.

Table 2. Time and distance between detections of *D. sublimbalis* in India, Papua New Guinea and Torres Strait and inferred rates of spread.

FROM (Place and Year)	TO (Place and Year)	Distance (km) from previous detection	Time since previous detection (years)	Rate of spread (km/ year)
India – Darjeeling to successive detections south				
Darjeeling (1903)	Calcutta (1945)	530	42	13
Darjeeling (1903)	Puri, Orissa (1952)	880	49	18
Darjeeling (1903)	Godavari, Andhra Pradesh (1993)	1400	90	16
		Average rate of spread (km/year)		**15**
PNG – shortest distance to each successive detection				
Kokoda (1933)	Gabumi, Madang (1958)	300	25	12
Kokoda (1933)	Port Moresby (1963)	95	30	3
Cyclops Mts, West Papua, Indonesia (1936)	Telefomin, Western Province (1959)	305	23	13
Port Moresby (1963)	Saibai (Torres Strait) (1990)	500	27	19
		Average rate of spread (km/year)		**12**
Torres Strait				
Saibai (1990)	Dauan (1996)	18	6	3
Saibai (1990)	Moa (1998)	95	8	12
Moa (1998)	Badu (1999)	10	1	10
Saibai (1990)	Darnley (2000)	118	10	12
Saibai (1990)	Gabba (2000)	42	10	4
Badu (1999)	Hammond (2001)	48	2	24
		Average rate of spread (km/year)		**11**

* Note: Torres Strait average is included for interest only as the average falls within Australian and overseas examples. It is recognised that only jump dispersal could occur between islands.

Wind assisted spread

The 'jump dispersal' of *D. sublimbalis* in Torres Strait (see Fig. 2 and Table 2) could be from human assisted movement of larvae in fruit and/or wind assisted movement of adult moths. Spread between islands has entailed movement of up to 118 km from the original detection on Saibai in 1990 (see Table 2).

D. sublimbalis adults are known from July to December in Papua New Guinea, with populations peaking in September and October (Gibb *et al.* 2007). Spread in the Torres Strait may be either southwesterly or southeasterly from the original detection on Saibai, or southeasterly from mainland PNG. Winds in the Torres Strait are predominantly SE from April to November and NW from December to March (BOM 1999, 2008).

NW winds (causing movement in a SE direction) may have carried moths from: PNG Western Province to any of the infested Torres Strait islands; Saibai to Darnley; or the central islands to Somerset (see Fig. 3). These winds are known to transport other insect pests: NW winds have been frequently strong enough to transport mosquitoes from PNG to Badu Island (Ritchie and Rochester 2001) and NAQS surveillance traps regularly catch exotic fruit flies from PNG on eastern and central Torres Strait islands. However, NW winds begin in December, the month when *D. sublimbalis* populations are declining in PNG. This may make wind-blown dispersal a less likely event, unless dispersal is triggered late in the season when fruit resources are being exhausted by *D. sublimbalis* larvae. If such wind-assisted movement were possible, it could have serious implications for the spread of *D. sublimbalis* south of the NPA to the rest of Queensland. The nearest known mangoes south of the NPA communities are 80 km away at Heathlands ranger base. However, these mangoes have been surveyed annually by Queensland Primary Industries and Fisheries (QPIF) staff since 2001, with no detections of *D. sublimbalis* made to date.

Human assisted spread of larvae

D. sublimbalis is capable of being moved long distances in infested fruit carried for human consumption. All fruit found to be infested with *D. sublimbalis* in the NPA by QPIF staff have shown some external signs of damage, which reduces the likelihood of them being carried by people for food. However, fruit with first instar larvae just under the skin exhibit less obvious damage, with only a small entry hole and pale sap stain. Half-ripe mangoes are a popular food source in the NPA and Torres Strait and it is possible that fruit infested with first instar larvae could be carried long distances. Human assisted spread of larvae could account for the large movements between islands in the Torres Strait but does not appear to have been important in the dispersal in the NPA.

In relation to the risk of fruit with only eggs (*i.e.* not exhibiting any damage) being moved, Krull (2004) found that only a small proportion of the eggs (1.92%) were laid on fruit in PNG, the rest being laid on the peduncle or branch. Where eggs were laid on the fruit, they were most often on marble sized fruit or, rarely, on mature fruit and always in crevices such as anthracnose spots. Fruits with these characteristics are less likely to be transported for eating.

Natural movement of *D. sublimbalis* out of the NPA is unlikely as the nearest population of hosts is over 80 km south at Heathlands, a small isolated ranger base harbouring only 12 host trees. The vegetation between Heathlands and the NPA is largely low, dry heath unsuitable for mangoes, forming a natural buffer through lack of hosts. However, dispersal assisted by strong wind events, as observed for other insect pests in Torres Strait (Ritchie and Rochester 2001), or with human intervention, is possible.

The natural dispersal rate of *D. sublimbalis* in the NPA (averaging 7 km/year) provides an estimate that could be applied in formulating control and surveillance programs and in defining quarantine areas where *D. sublimbalis* has established in mango production areas. Such programs would, however, need to take into account the possibility that assisted dispersal over long distances may also occur.

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